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Measures of Merit for Command and Control in the Context of Network Centric Warfare

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ICIAM 2003
5th International Congress on Industrial and Applied Mathematics
SYDNEY, AUSTRALIA • 7-11 JULY 2003

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
01 OCT 2003	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Measures of Merit for Command and Control in the Context of Network Centric Warfare	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Land Operations Division Defence Science and Technology Organisation, Australia**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001929. Proceedings, Held in Sydney, Australia on July 8-10, 2003., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**20**	

Contents

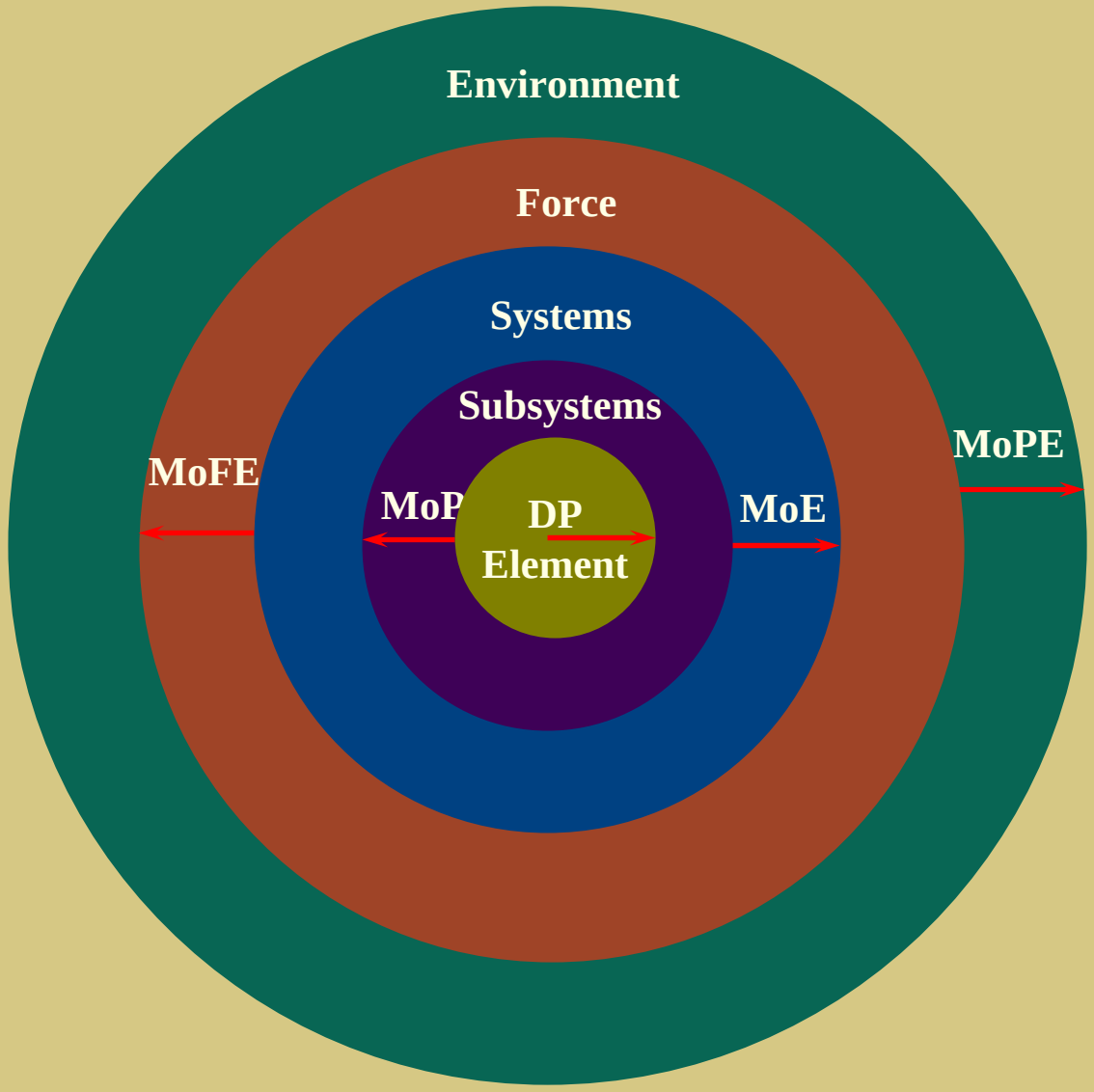
- Background
- Measures of Merit (MoMs) frameworks
- C2 MoMs in the NCW context
- Aggregation of MoMs
- An application in a MOLE scenario
- Conclusions

1. Background

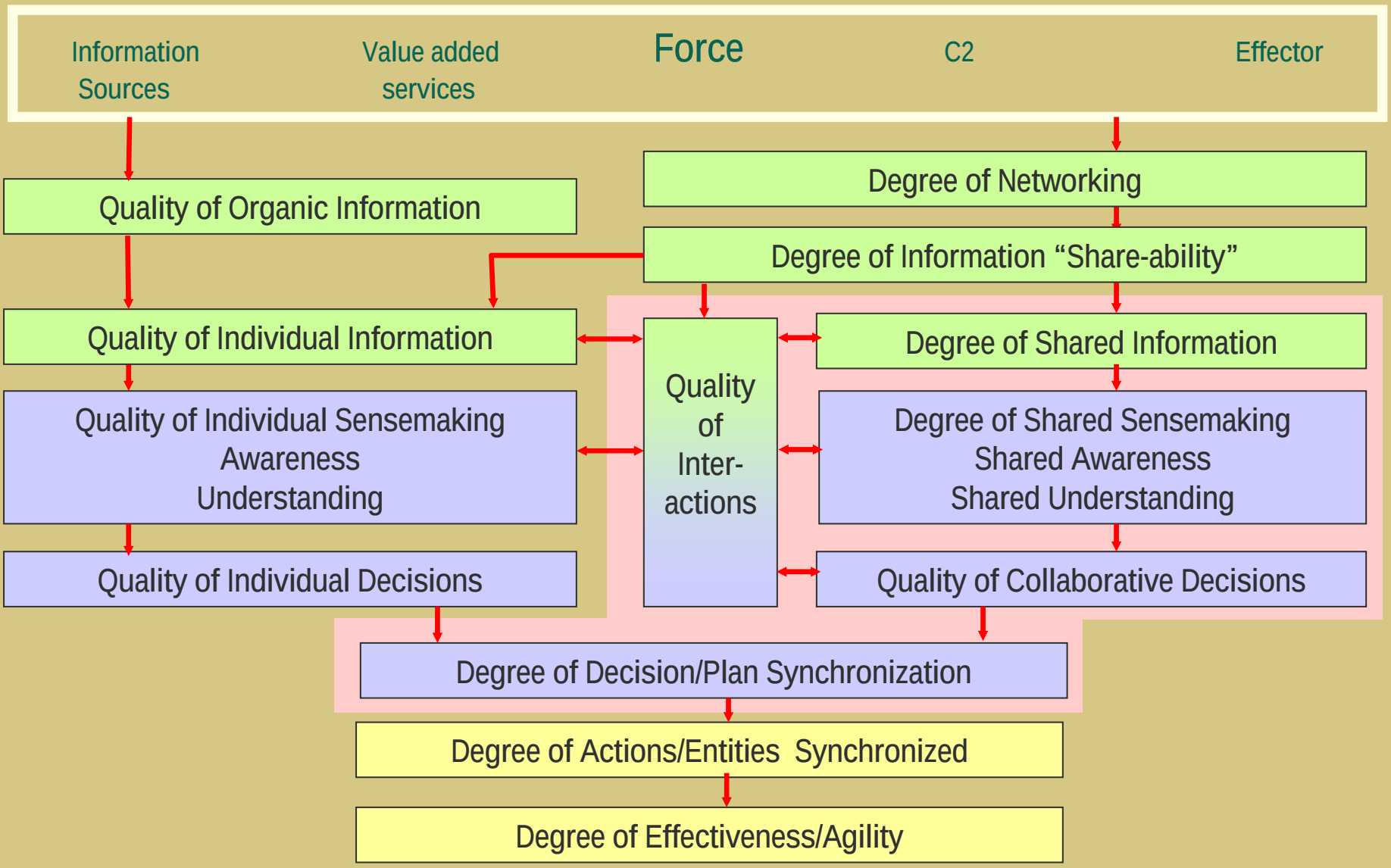
- C2 systems are adaptive control systems
- Traditionally control over selected aspects of battle environments
- NCW creates an integrated system
- NCW hypothesis:
  - C2 system performances are enhanced by information technology and pervasive networking infrastructures
  - Drastic improvement in overall force effectiveness
- MoMs to test the hypothesis and compare alternative C2 systems
- Aggregate MoMs at each node and over the network

2.1 MoM Framework – MORS

- Four-level hierarchy of measures (1986)
- Adopted by NATO Code of Best Practice for C2 Assessment (2002)
- One additional level added to account for OOTW
- Generic



2.2 MoM Framework – US NCW



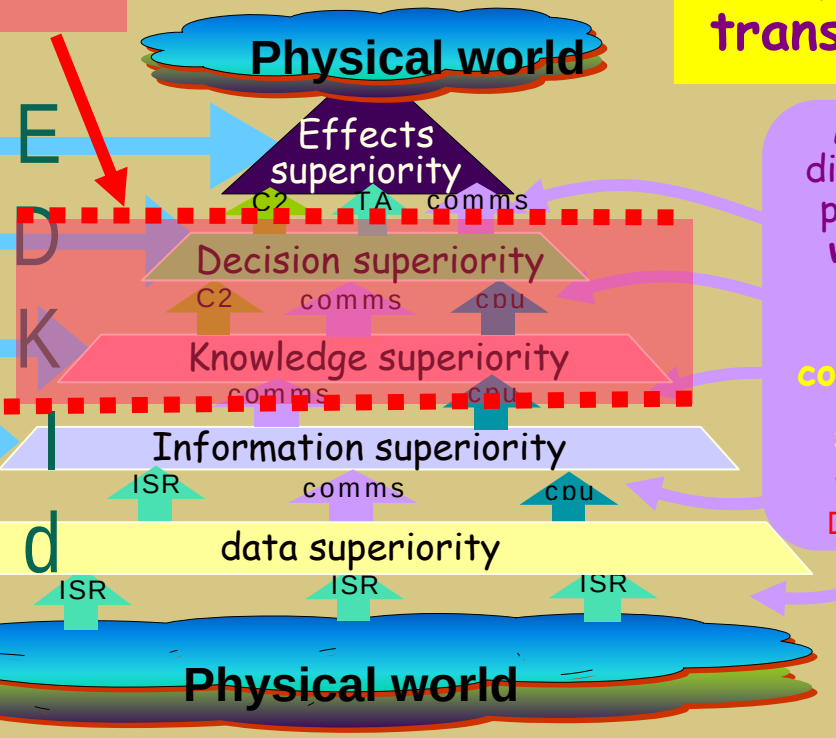
2.3 MoM Framework – Knowledge Analysis Framework

Focus on Human Performance and roles and HMI's

INSIGHT:Role of C4ISR systems is to enable transitions between layers

Measure achieved performance in successive **layers** to → effectiveness of transitions between layers

HOW WELL ARE WE DOING?



Measure or dictate C4ISR performance **within each transition**

→ C4ISR contribution to K,D,E superiority

WHAT ARE WE DOING IT WITH?

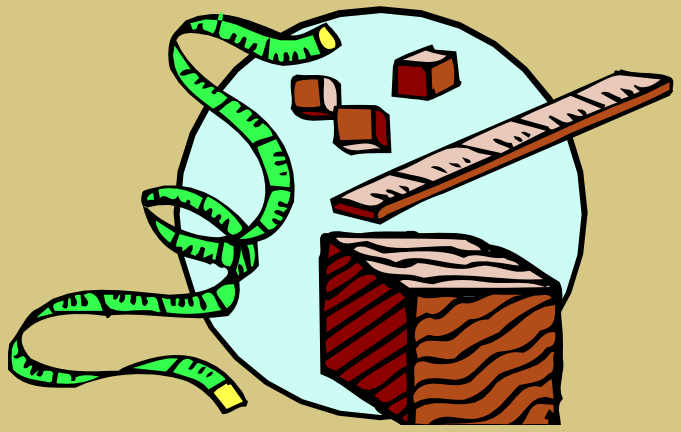
result

What we can change

KAF draws explicit relationship between performance metrics of C4ISR systems and military effectiveness

3.1 MoM

- A generic term that refers to the metrics by which systems are measured, assessed and compared
- Measurability
  - Quantitative (usually physical domain, objective) or qualitative (usually cognitive domain, subjective)
  - Measurement unit/scale
  - Direction of improvement (the more the better, the less the better, target is best)
- Three types of measures
  - Rank or ordinal
  - Relative value
  - Absolute value



3.2 Are C2 MoMs in NCW context different?

- "Identify and measure key features of NCW and relate these characteristics to the measurement hierarchy"
- Basic functions of C2 will not change
- Some key features of NCW
  - Linking of battlespace entities with the transport of information
  - Wide application of information technologies
  - Emphasis on shared awareness
  - Information enabled organisations
  - Self-synchronisation

- MoMs that can assess the impact of NCW features on basic C2 functions and mission objectives
- Establish causal links

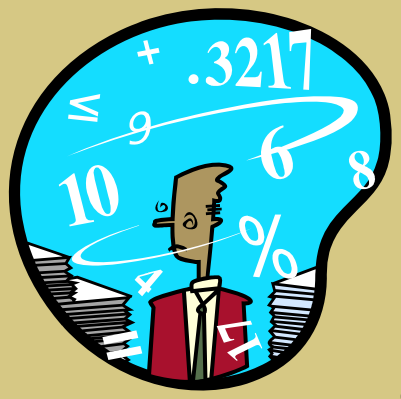
3.3 Examples of C2 MoMs in NCW Context

- Node connectivity
- Degree of transparent information sharing
- Percentage of right information provided to the right node at the right time
- Effectiveness of battlespace visualisation system
- Consistency of situation assessments
- Percentage of time when planners can conduct distributed/virtual planning
- Availability and utility of decision support tools
- Degree to which specific effects are synchronised over time, geography and emergent events
- Ability to apply right effects on the right targets

4.1 Aggregation of MoMs (1)

- ADF effectiveness: function of scenarios and missions
  - Versatility, vulnerability, survivability, adaptability
- Aggregation can happen at all levels (except the bottom one) of the measurement hierarchy
- Multi-Criteria Decision-Making (MCDM)
  - Direct aggregation methods: SAW, MEW, utility function
  - Pair-wise comparison methods: AHP, CA
  - Comparison-with-ideal methods: TOPSIS
  - Outranking methods: ELECTRE, PROMETHEE, ORESTE
  - Programming methods: DEA
  - Fuzzy logic methods
  - Probabilistic methods

4.1 Aggregation of MoMs (2)



- Constrained optimisation
  - Objective function: linear or nonlinear combination of MoMs
  - System/state equations: relationships of MoMs
  - Definitions/aggregations
  - Constraints
- Statistical Modelling
  - Structural equation model (SEM)
  - Impact/structural coefficients among same level of MoMs
  - Impact/structural coefficients between an MoM and its component MoMs or the weights for aggregation
  - Various reliability measures
- Web based repository of C2 MoMs and data
  - To enable re-usability/exploitability of existing MoMs and data

4.2 The Repository's NCW Indicators

- NCW intensity coefficient

  The ratio of the number of NCW-related indicators to the total number of MoMs

- NCW power coefficient

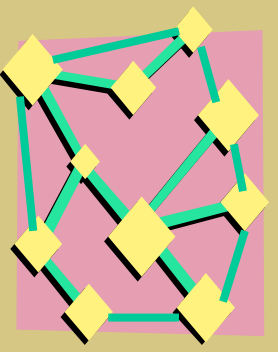
  The ratio of the sum of NCW-related indicators' ratings to the sum of all MoMs' ratings

- Genuinely network centric MoMs
  - Explicitly exploits the underlying network structure
  - Based on classical network optimisation techniques and graph theory
  - Can be optimised with respect to both the network structure and any additional constraints that may be relevant to the measure

4.3 Network Flow Optimisation Problem

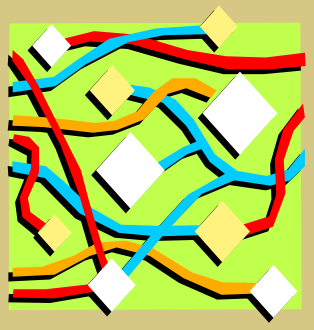
- A given network of fixed capacity $\mathcal{N} = < N, \mathcal{A}, u >$
  - N is a finite set of *nodes*
  - $\mathcal{A} \subset \{(i, j) \mid i, j \in N\}$ is the set of *arcs*
  - u is a vector of capacities u_{ij} for all $(i, j) \in \mathcal{A}$ and assuming $u_{ij} \geq 0$
  - Flow on $\mathcal{N}$ is a vector x whose coordinates x_{ij} for $(i, j) \in \mathcal{A}$ satisfy $0 \leq x_{ij} \leq u_{ij}$; $(i, j) \in \mathcal{A}$
- Classical network flow optimisation problem
  - Coefficient matrix A captures constraints on the flow
  - A linear objective function with predefined coefficient matrix c

$$\begin{aligned} &\text{Max} && c^T x \\ &\text{Subject to:} && A x = b \\ & && x \leq u \qquad (N_f) \\ & && x \geq 0 \end{aligned}$$



4.4 Formulating a genuinely NCW MoM

- For a particular MoM, the flow x_{ij} on an arc $(i, j) \in \mathcal{A}$ can be
  - A possible value of the MoM associated with the arc, or
  - The "weight" associated with (i, j) for that MoM
- Suppose x^0 and $z^0 := c^T x^0$ are an optimal solution of (N_f)
- We can define genuinely network centric MoM as
  - $z^0 = \max c^T x^0$, or
  - $\sum_{(i, j) \in \mathcal{A}} x^0_{ij}$ MoM_{ij}, where MoM_{ij} is the part associated with arc (i, j)
- The virtue is that the underlying graph theoretic structure of $\mathcal{N}$ is incorporated in the definitions
- There are other researchers investigating mathematical metrics, eg. Perry and Bowden's work



5.1 A MOLE scenario

5.2 Constructing Node Connectivity MoM

- Definitions
  - Simple connectivity *X*

    $x_{ij} \in \{0,1\}$ and $\sum_{i \le j} x_{ij} = 0$
  - Criticality of connections *C*, where c_{ij} is determined by information exchange requirements between nodes
  - Costs *A*, where A_{ij} depends on the actual type of communication systems used to provide the connection
- The optimisation problem with a cost limit of *b*
  - Max $\sum_{(i,j)} c_{ij} x_{ij}$
  - Subject to $\sum_{(i,j)} A_{ij} x_{ij} \le b$ and

    There exists a path from every i to every j.
- The optimised node connectivity

  The optimal value of the objective function $\sum_{(i,j)} c_{ij} x_{ij}^{0}$

5.3 Comments about aggregation of higher level MoMs

- NCW C2 issues are usually complex and poorly defined
- The elusive and intangible nature of the problem presents real challenges for modelling relationships among MoMs
- Additive aggregation (especially at a higher level) is a rudimentary first order approximation
- Does not capture non-linearity, or sometimes chaos, resulting from dynamic interactions of composing MoMs
- Used properly can indicate rough tendencies of linear aspects, but can be swamped by non-linear aspects
- Can be used as a diagnostic tool to focus more detailed analysis or experimentation

5.4 Modelling Situation Assessment MoM

- Definitions
  - Individual node situation assessment S_i (average over time)
  - In the context of situation assessment, criticality of cooperation C, where c_{ij} is determined by the need of cooperation between nodes (a very crude approximation)
  - Cooperation coefficients X, where x_{ij} describes the level of cooperation between nodes i and j
  - u_{ij}, determined by communication links, is the maximum possible value of x_{ij}
  - Processing power P, where p_i depends on the nature of the node
- The optimisation problem
  - Max $\sum_{(i,j)} c_{ij} x_{ij}$
  - Subject to $\sum_{(j)} x_{ij} \le p_i$ and $x_{ij} \le u_{ij}$
- The resulting situation assessment $\sum_{(i,j)} x_{ij}^0 \hat{S}_i \hat{S}_j$ where $\hat{S}_i = S_i / \sum_k S_k$
- To what degree this indicator represents situation assessment?

6. Conclusions

- NCW infiltration into the thinking of C2 MoMs
- Reviewed existing MoM frameworks
- Adjustment of C2 MoMs in the NCW context
- Discussed concepts of NCW-intensity and NCW-power to make a MoMs repository progressively more network centric
- Some quantitative techniques for hierarchical aggregation of MoMs
- Indication of how genuinely network centric MoM could be constructed
- An example in MOLE
- A lot more work need to be done in this area

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